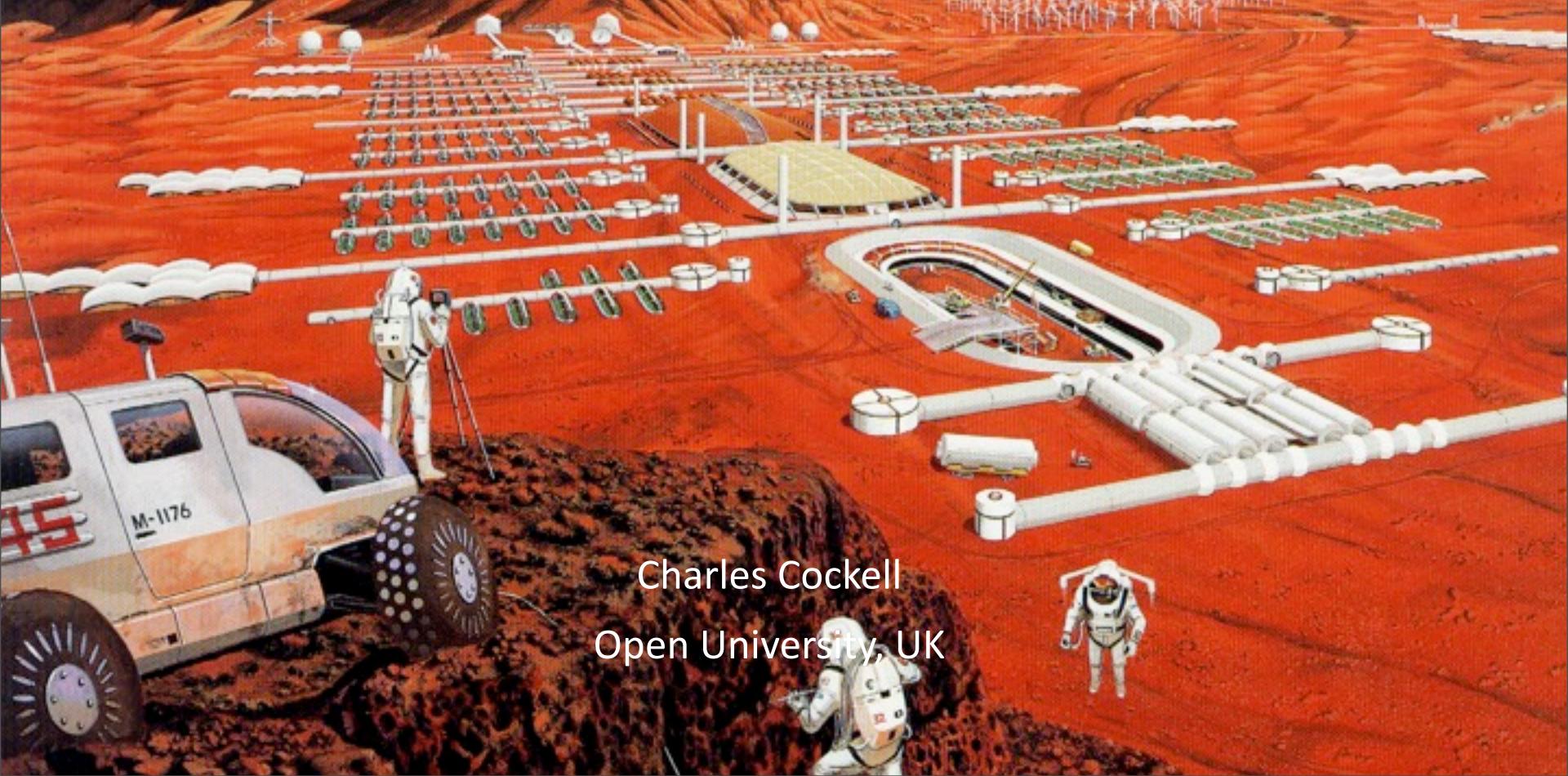
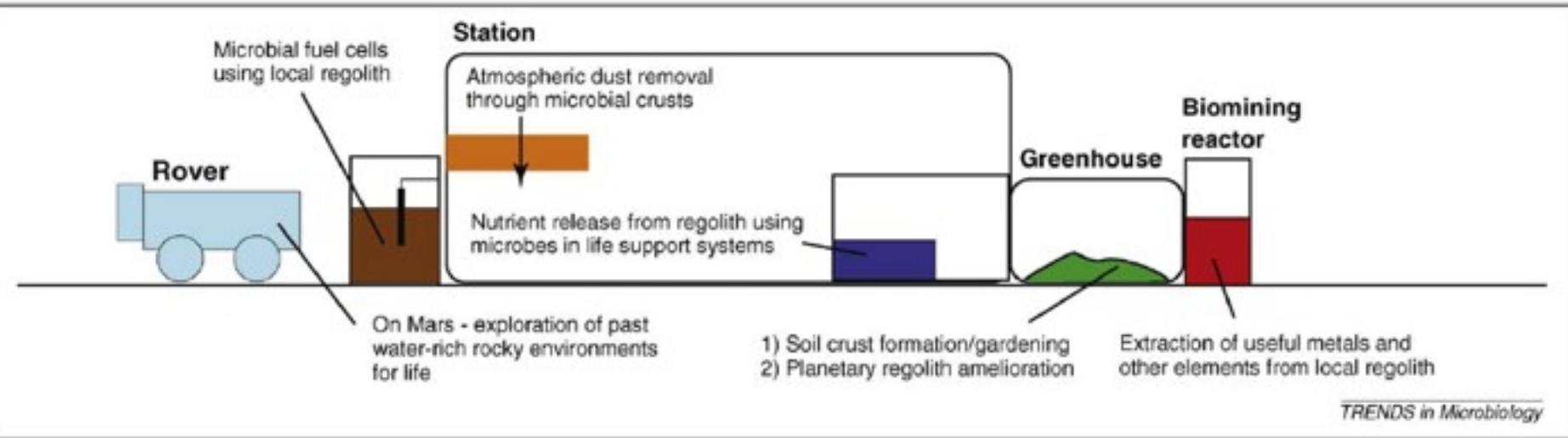


Synthetic microbes and rocks - geomicrobiology for human space settlement



Charles Cockell
Open University, UK

Geomicrobiology in space exploration and settlement

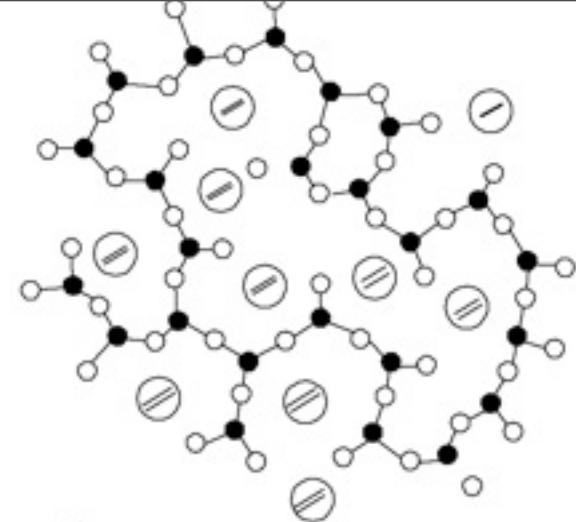
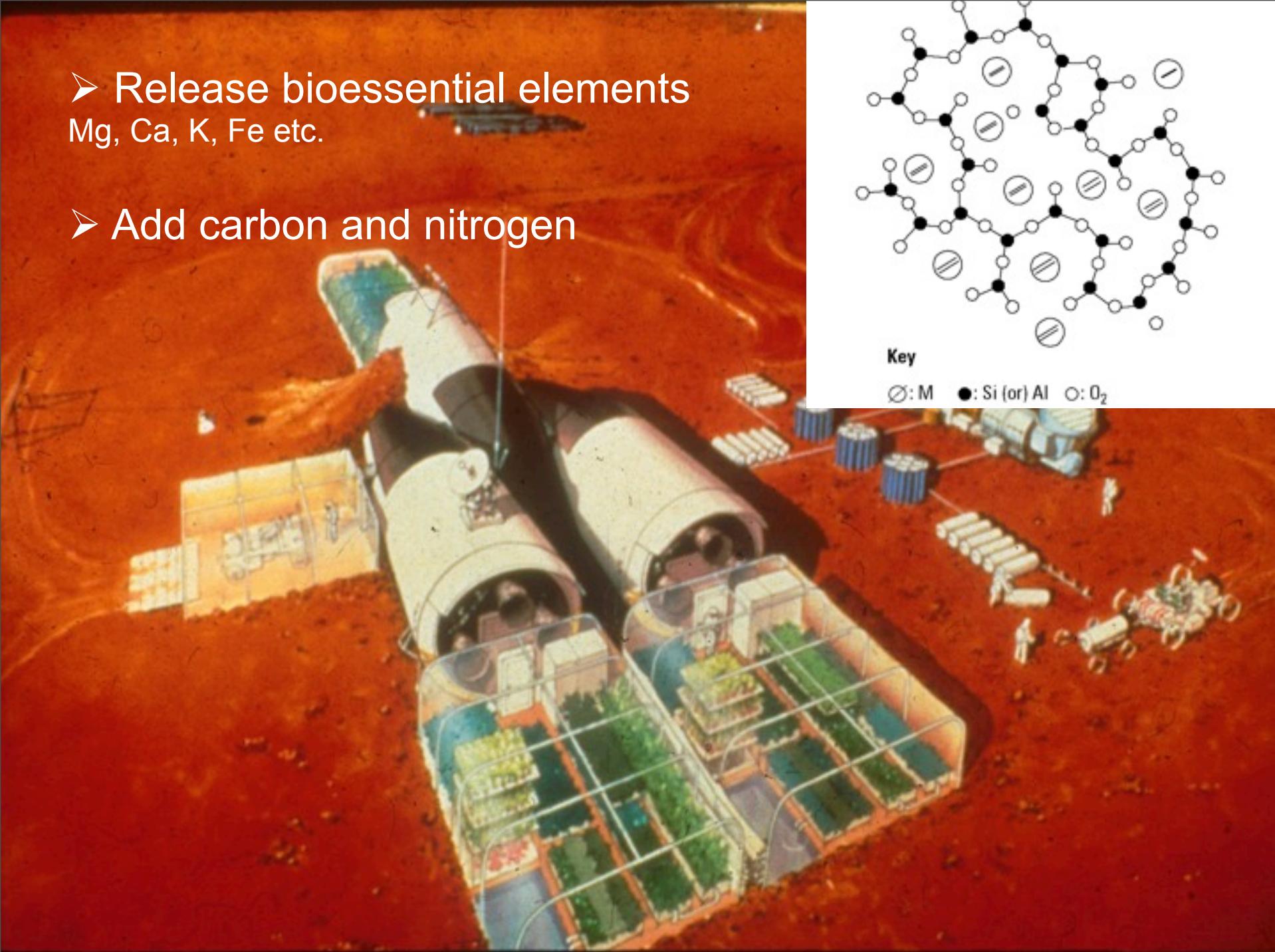


Cockell CS (2010) Trends in Microbiology 18, 308-314

- Weathering rocks to make soils / feedstock for microbial life support
- Biomining - extraction of industrially useful elements

- Release bioessential elements
Mg, Ca, K, Fe etc.

- Add carbon and nitrogen

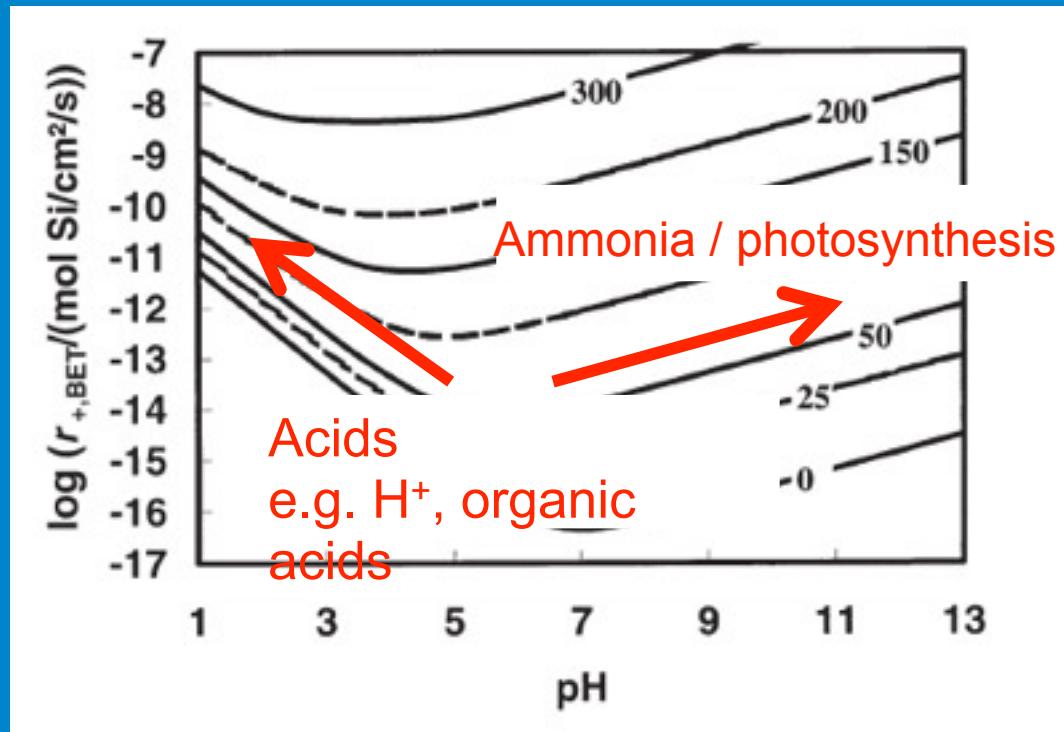


Key

○: M ●: Si (or) Al ○: O₂

Rock weathering

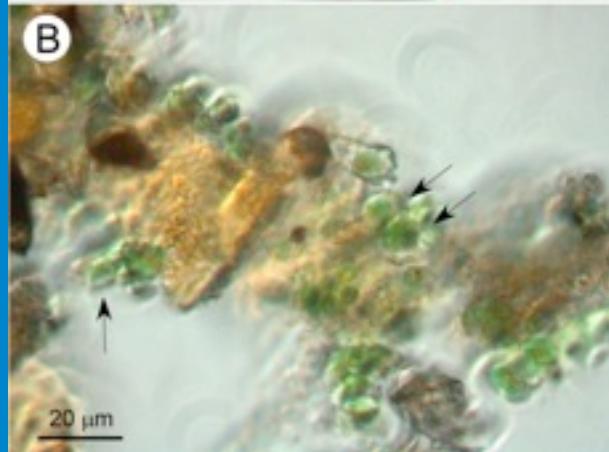
Basalt rock

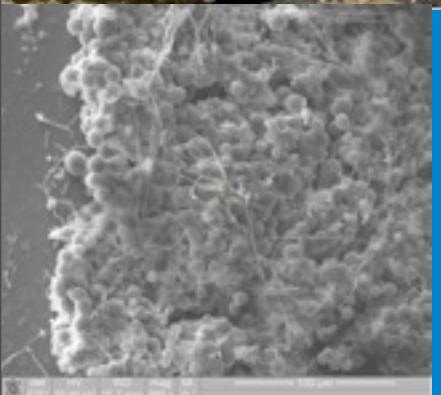
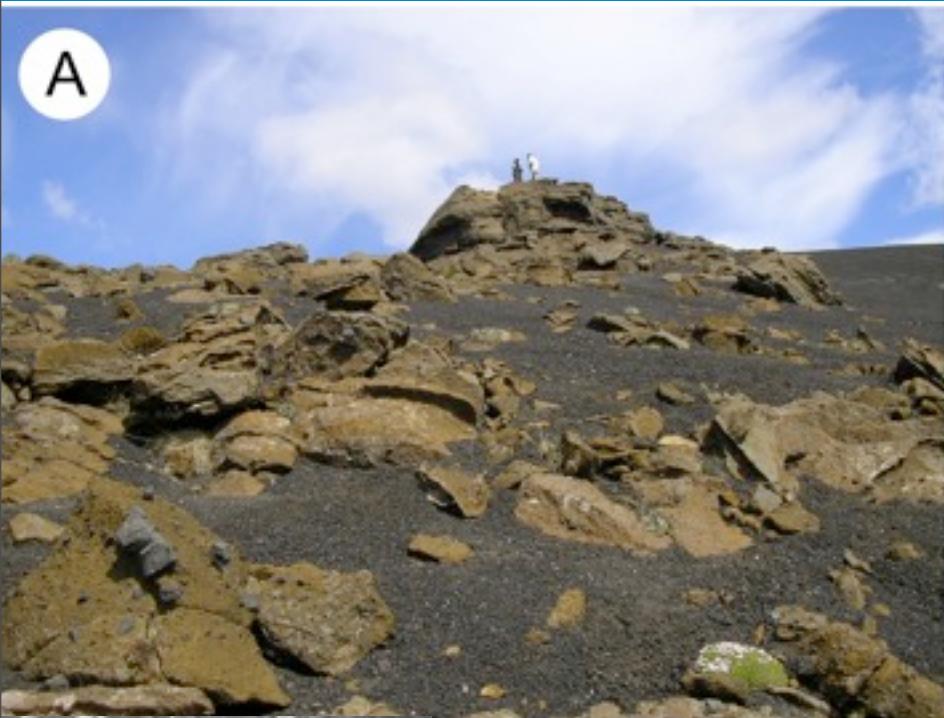


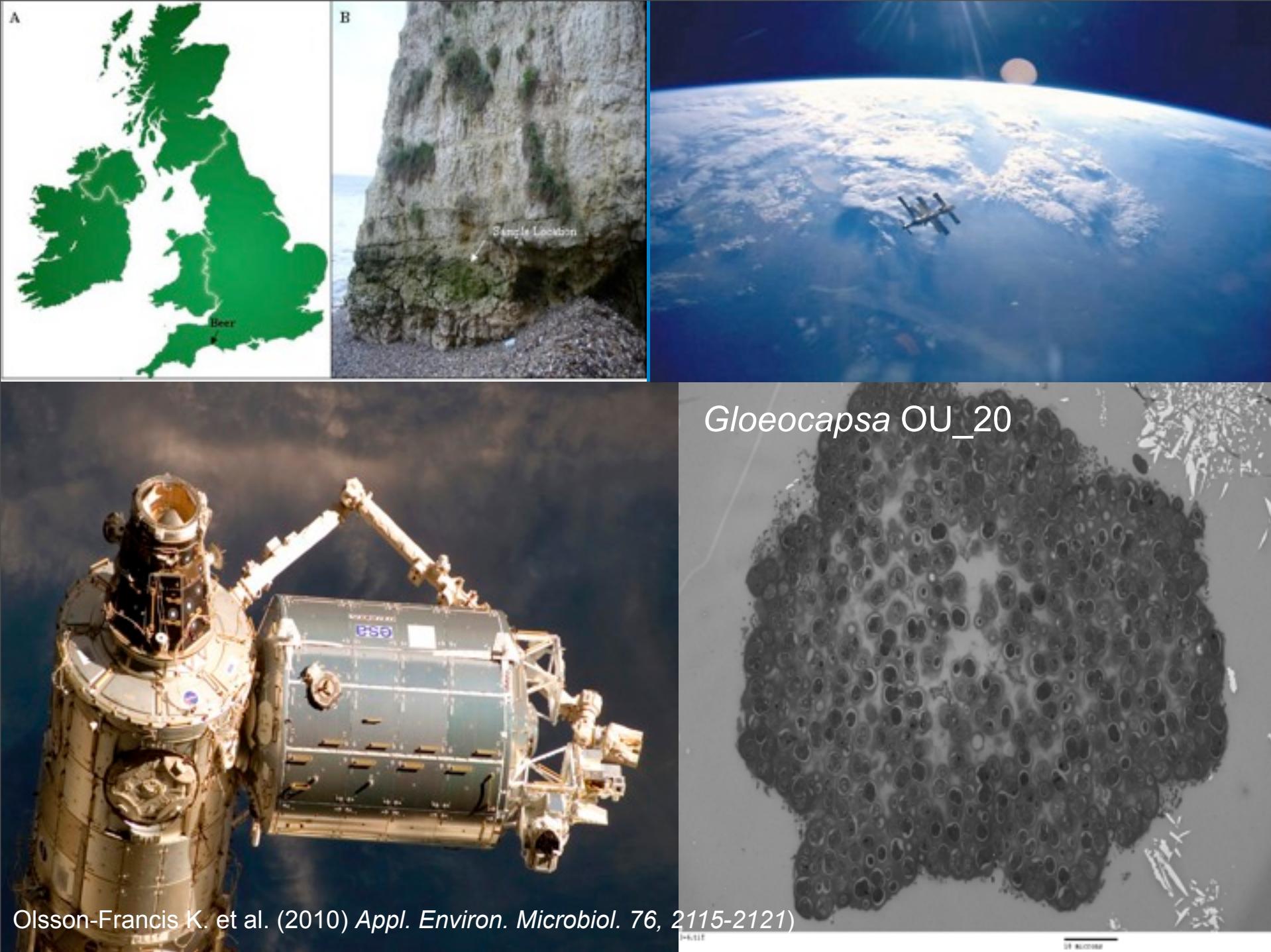
Gislason and Oelkers. 2003. GCA 67, 3817-3832

Cyanobacteria and algae

- Fix carbon and nitrogen
- Break down rocks

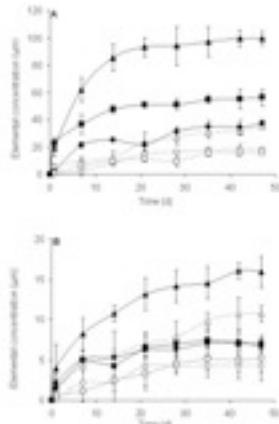




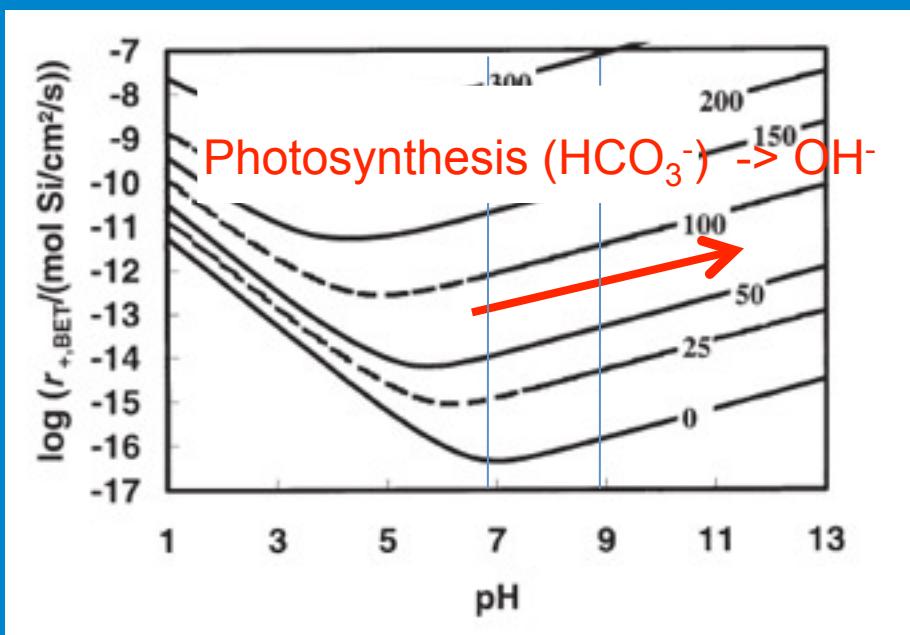
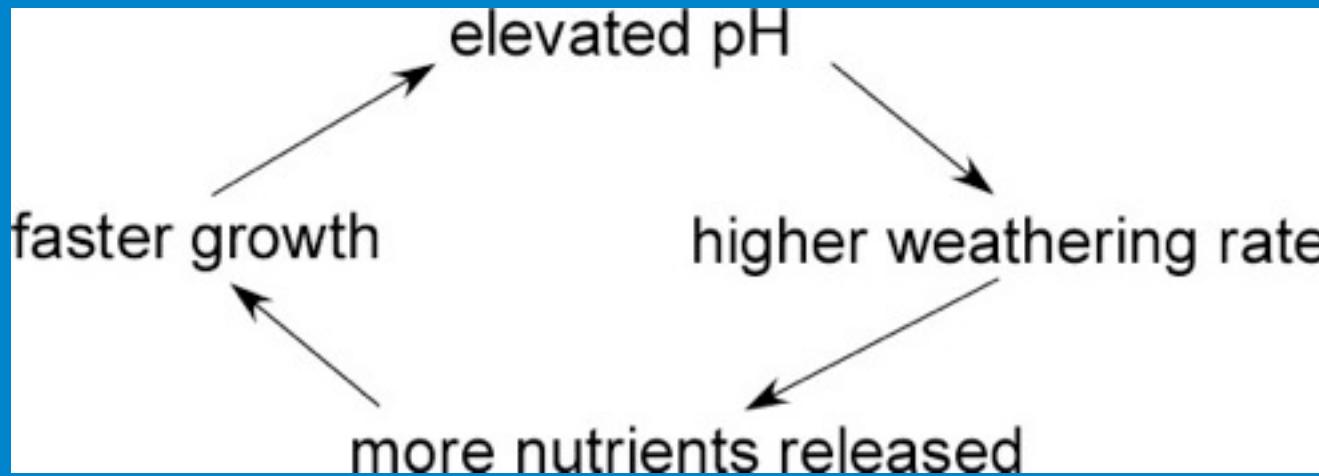


Cyanobacterial weathering:

Phormidium strain OU_10
Leptolyngbya strain OU_13
Synechococcus elongatus
Chroococcidiopsis sp. 029
Gloeocapsa strain OU_20
Anabaena cylindrica



	<u>Basalt (control)</u> Rhyolite (control)	<u>Basalt (biology)</u> Basalt (control)	<u>Rhyolite (biology)</u> Rhyolite (control)	<u>Basalt (biology)</u> Rhyolite (biology)
		\bar{R}_i^{be}		
Silica	3.76	11.14	1.82	22.75
Calcium	2.66	4.94	1.55	8.47
Magnesium	2.83	7.27	1.54	13.33
		C_i^{eq}		
Silica	4.05	3.98	1.49	10.80
Calcium	4.39	3.28	1.56	9.22
Magnesium	3.07	5.01	1.35	11.38



A PROBLEM

Space tolerant species are generally not fast growing or good at weathering

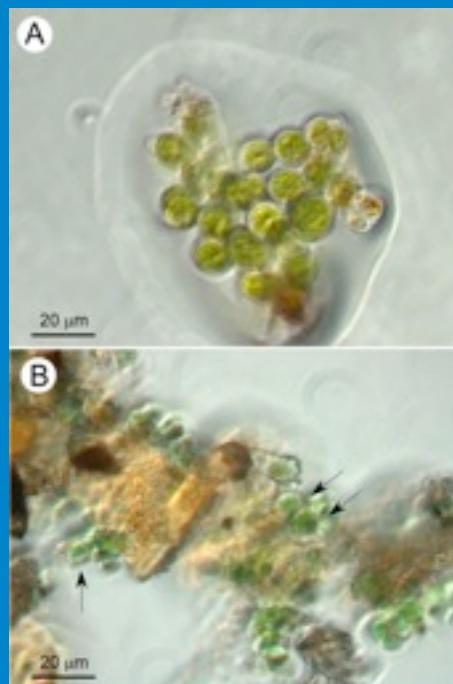
	Si (10^{-12} mol/m 2 /s)	Mg	Ca
<i>Anabaena cylindrica</i>	1.443	0.903	0.973
<i>Phormidium</i> strain OU_10	0.394	0.713	0.962
<i>Leptolyngbya</i> strain OU_13	0.891	0.482	0.702
<i>Synechococcus elongatus</i>	0.915	0.704	0.841
<i>Chroococcidiopsis</i> 029	0.299	0.556	0.623
<i>Gloeocapsa</i> strain OU_20	0.366	0.327	0.609
Mean	0.718	0.614	0.785
Control	0.113	0.273	0.078

Cockell CS, Olsson-Francis K. Planet Space Sci. 58, 1279-1285

SYNTHETIC BIOLOGY?

How to build a ‘Super Weathering Microbe (SWEM)’

- Upregulate either photosynthesis or acid production to increase weathering
- Enhance tolerance to desiccation (for storage)
- Enhance tolerance to ionizing radiation to improve ‘space-worthiness’ (using genes from space-tolerant organisms)
- **Maintain high growth rate**





Biomining

“The Basalt Economy”

Industrial Uses of Volcanic Rock Elements

Si – solar cells, glass, ceramics

Al – lightweight metals, alloying, varnishes, glass, ceramics

Ca – alloying, steel production, cements

Mg – die castings, alloy production, batteries, flares

K – soaps, glassware

Na – heat transfer agents, lighting, organic syntheses

V - Carbon dioxide cracking

Ni – catalysis, methane production

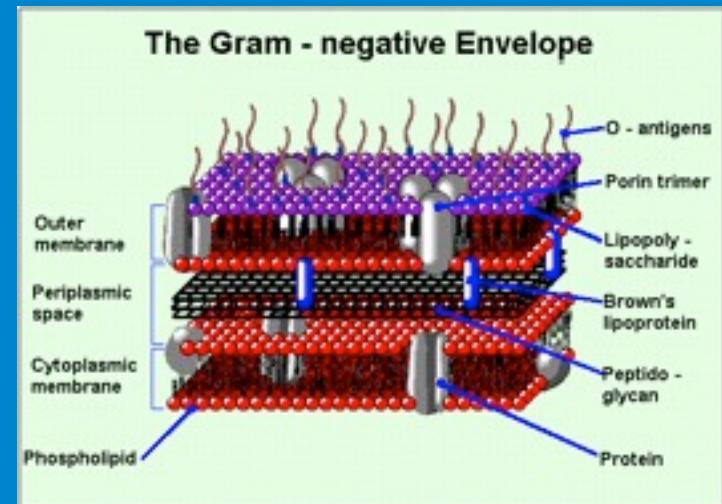
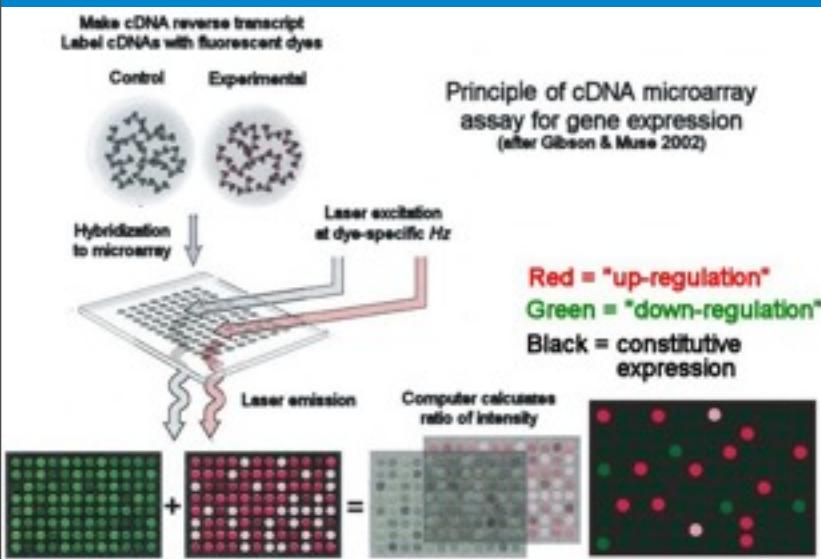
Cu – catalysis

Zn – protective coatings, paint, batteries

Cd – alloy coatings

Biomining

Which genes are involved in microbe-mineral interactions?



Cupriavidus metallidurans

Gen	Gene function	Fold
Rmet_1628	Putative transmembrane outer membrane porin signal peptide protein	15.427
Rmet_1149	Lipid-A-disaccharide synthase; tetraacyldisaccharide-1-P synthase	2.653
Rmet_1139	Putative MFS transporter	2.119
Rmet_5973	Sodium:solute transporter	2.00
Rmet_4961	Fimbrial protein	1.963



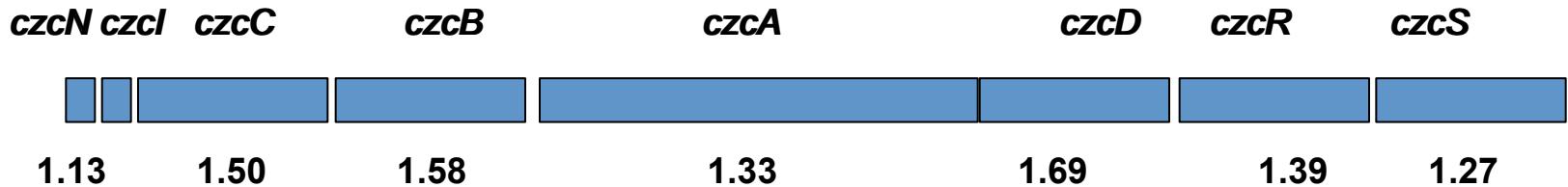
Olsson-Francis et al.
2010. *Geobiology* (in press)

Acquisition of iron from volcanic rocks involves exposure to heavy metals

Genes involved in heavy metal transport				
<i>czcD</i> (pMOL30)	Cation diffusion facilitator (CDF)	1.69	9.90E-05	
<i>czcB</i> (pMOL30)	Membrane fusion protein, tricomponent cation/proton antiporter efflux system	1.58	4.25E-04	
<i>czcC</i> (pMOL30)	Outer membrane protein, tricomponent cation/proton antiporter efflux system	1.50	1.01E-03	
<i>czcR</i> (pMOL30)	Response regulator of two component regulatory system	1.39	2.72E-03	
<i>czcA</i> (pMOL30)	Efflux chemo-osmotic pump, tricomponent cation/proton antiporter efflux system	1.33	5.05E-03	
<i>czcS</i> (pMOL30)	Sensor histidine kinase of two component regulatory system	1.27	8.15E-03	
<i>cnrA</i> (pMOL28)	Inner membrane efflux pump, tricomponent cation/proton antiporter efflux system	1.89	4.25E-04	
<i>cnrT</i> (pMOL28)	Cation diffusion facilitator (CDF)	1.58	3.94E-04	
Rmet_5670	Copper resistance protein B (copB2), outer membrane protein	2.01	5.75E-06	
Rmet_5669	Copper resistance C (copC2) protein precursor	1.50	1.04E-02	
Rmet_5671	Copper resistance protein A, multi-copper oxidase (copA2)	1.23	1.54E-02	
Rmet_4120	HmyC, outer membrane porin, cation tricomponent efflux system (CzcC-like)	1.92	6.12E-04	
Rmet_4121	HmyB, membrane fusion protein, cation tricomponent efflux system (CzcB-like)	1.85	1.08E-03	
Rmet_4123	HmyA, efflux pump, cation tricomponent efflux system (CzcA-like)	1.44	6.36E-04	
Rmet_4595	ZntI, regulator (CzcI-like)	1.69	1.67E-03	



Czc operon – induced by Cd^{II}, Zn^{II} and Co^{II}



One way to extract elements

V



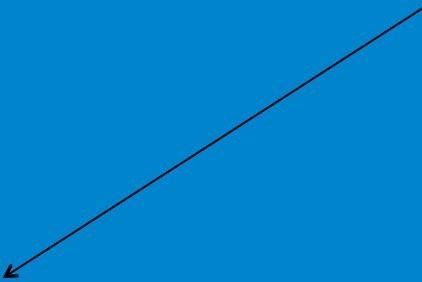
1. Engineer vanadium sequestering microbes



2. Add to basalt in growth media



3. Collect leachate

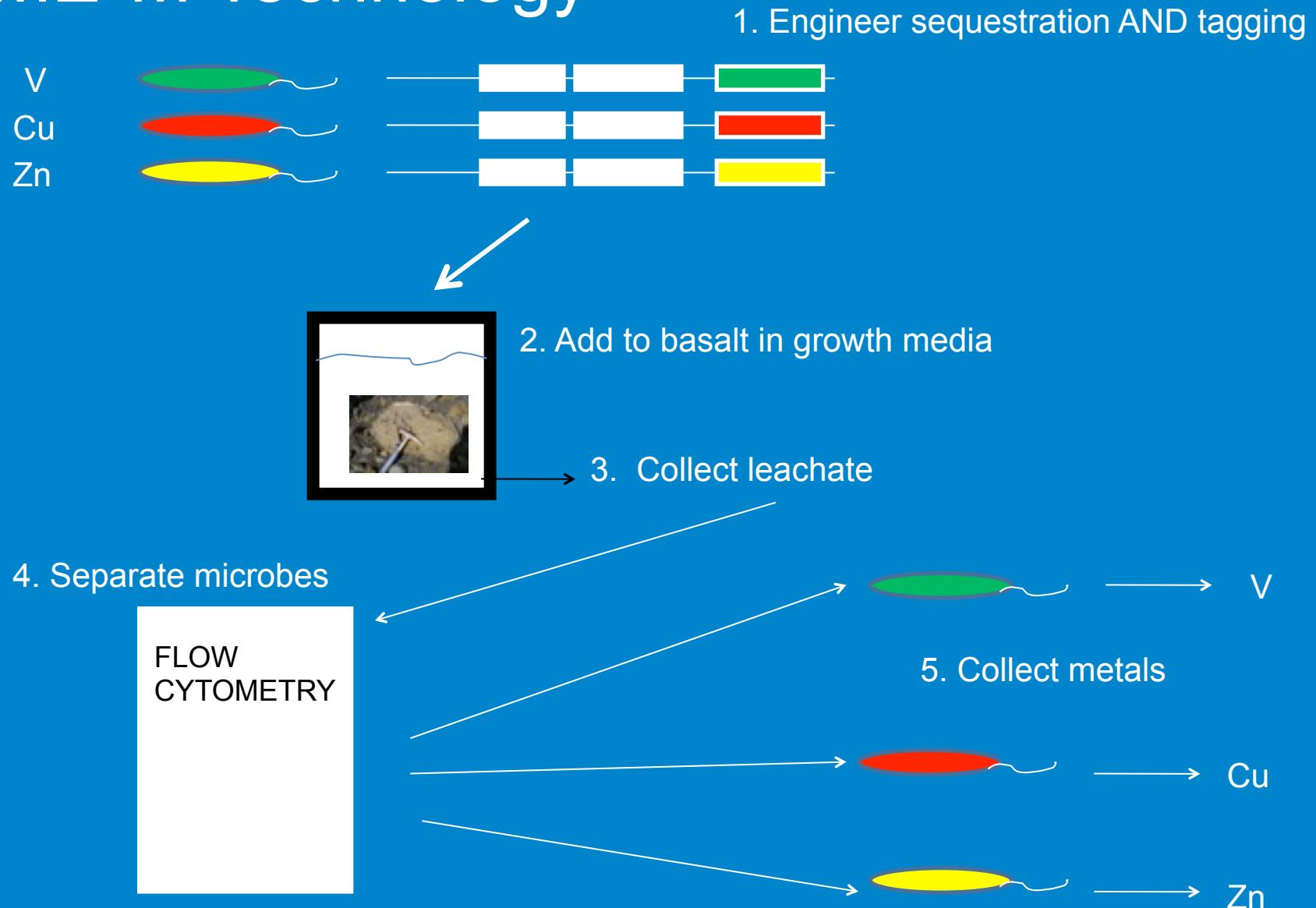


4. Break up microbes and extract vanadium

5. Do this with different elements

Another way:

ME⁴M Technology



CONCLUSIONS

- Knowledge of the mechanisms and genetics of weathering can be used to create Super Weathering Microbes (SWEMs) for amelioration of extraterrestrial regolith.
- Manipulation of metal sequestration genes might be used to generate new approaches to biomining. Creation of metal sequestration microbes and separation using fluorescent or colour tagging might allow specific extraction of metals.
- Synthetic biology can be used to drive the basalt economy – one basis of extraterrestrial industrial self-sufficiency and wealth creation.

Acknowledgements



Geomicrobiology
Research

Group

Laura Kelly

Karen Olsson

Aude Herrera

Paul Wilkinson

Annika Simpson

Stephen Summers

Tatjana Polacsek



Open University, UK

Thorsteinn Thorsteinsson
Viggo Marteinsson

Leverhulme Trust
Royal Society
NERC Centre for Ecology and Hydrology
STFC